FIRST AMENDMENT TO

ANNEX IX

OF THE

IMPLEMENTING AGREEMENT

BETWEEN

THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA

AND

THE MINISTRY OF ENERGY AND MINES OF THE REPUBLIC OF VENEZUELA

IN THE AREA OF

SUBSIDENCE DUE TO FLUID WITHDRAWAL

WHEREAS, the United States Department of Energy (hereinafter referred to as DOE) and the Ministry of Energy and Mines of Venezuela (hereinafter referred to as MEMV) desire to cooperate in the field of energy research and development;

WHEREAS, in the furtherance of their mutual interest DOE and MEMV entered into the Agreement in the field of Energy Research and Development signed March 6, 1980 (hereinafter referred to as the Energy R&D Agreement);

WHEREAS, on July 12, 1983, DOE and MEMV entered into an Implementing Agreement in the area of subsidence due to fluid withdrawal (hereinafter referred to as the Implementing Agreement);

WHEREAS, DOE and MEMV have a mutual interest in technology exchange on the prediction of subsidence as a result of fluid withdrawal;

WHEREAS, DOE and MEMV have a mutual interest in improving their present modeling capability to predict the occurrence of cracks produced by subsidence due to fluid withdrawal and/or removal of subsurface material;

WHEREAS, an ability to predict the occurrence of the potentially damaging effects of differential subsidence is of considerable value to many DOE and MEMV programs;

WHEREAS, near-surface cracking has been observed in oil fields of the Bolivar Coast, Venezuela, in response to discontinuous differential subsidence, providing a unique test area for the development and evaluation of predictive models for subsidence and horizontal deformation;

WHEREAS, some coastal dikes have been built to protect some inland areas presently below sea level at some densely populated zones and to maintain the oil and aquifer production from this area of the Maracaibo basin;

WHEREAS, approximately 80% of the Venezuelan daily petroleum production originates in the Maracaibo basin;

WHEREAS. Article 7 of the Implementing Agreement and Article V of the Energy R&D Agreement of March 6, 1980, provide that DOE and MEMV may amend the Implementing Agreement by mutual written consent;

It is agreed that the entire Implementing Agreement be replaced with the following:

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ARTICLE 1

In accordance with Article V of the Energy R&D Agreement, the Venezuelan representatives of the Steering Committee have designated INTEVEP, S. A. to act on behalf of MEMV under this Implementing Agreement. INTEVEP and DOE shall be hereinafter referred to as the Parties to this Implementing Agreement. The Assistant Secretary for Fossil Energy shall be primarily responsible for the programmatic aspects of this Implementing Agreement for DOE. Lawrence Livermore National Laboratory shall carry out DOE's technical responsibilities under paragraph A, B, and D of Article 2 of this Implementing Agreement. Each Party shall designate one Project Manager for this Implementing Agreement; these Project Managers shall provide technical management and coordination of the tasks described in this Implementing Agreement.

ARTICLE 2

The Parties shall cooperate in tasks in the area of subsidence due to fluid withdrawal as set forth below:

A detailed statement of work is provided in the Appendix to this Implementing Agreement.

A. Geophysical Probing

Task 1: LLNL shall provide INTEVEP with a detailed review of the geophysical techniques that have merit for determining the nature of fractures at three specific sites on the Bolivar Coast. Each of the above sites shall be considered in terms of its own underground characteristics, such as saturation, fluid composition, and material-type. The techniques to be evaluated shall include, but shall not be limited to, surface based electromagnetic radar, electrical self-potential, two-loop mutual impedence, electrical resistivity, seismic transmission, excitation-of-the-mass, borehole-to-borehole signal-transmission, and seismic emission.

Task 2: LLNL shall provide INTEVEP with recommendations for implementation of a reconnaissance system for detecting cracks and voids within the dikes along the Bolivar Coast of Lake Maracaibo.

Three methods shall be evaluated for monitoring the dikes, Mutual Impedence, Magnetometric Resistivity, and Excitation of the Mass. The first two techniques are for detecting and delineating voids in the dikes and the third for detecting seepage paths under the dikes. Based on these evaluations, LLNL shall design a system and plan an experimental program to test it. LLNL and INTEVEP will jointly review this plan and decide whether to proceed with system fabrication and field tests, as a continuation of this task: if the decision is made to proceed, such activities shall be the subject of a future Amendment to this Implementing Agreement.

INTEVEP shall acquire samples of materials from which dikes are made and ship these samples to LLNL for purposes of electrical characterization. Alternatively, INTEVEP shall provide to LLNL measured values or data from which the characterization can be derived. INTEVEP shall also provide detailed drawings of a representative dike.

Task 3: Fullwave Recording of Data from Acoustic Emission Experiment.

A decision to include this task shall be made by the Parties at a later date and, if included, it shall be the subject of a future Amendment to this Implementing Agreement.

Task 4: Swept-Frequency Radar Development.

A decision to include this task shall be made by both Parties, based on fixed-frequency radar investigations done by INTEVEP and, if included, it shall be the subject of a future Amendment to this Implementing Agreement.

B. Seismic Hazard Studies

Task 1: Structure and Seismicity.

a) Seismic Network Installation/Data Acquisition.

LLNL shall assist INTEVEP in developing a model for relocating current and past seismicity affecting the eastern Lake Maracaibo region by temporarily deploying portable digital recorders and LLNL's central recording system to collect waveform data from the INTEVEP network. These portable recorders shall remain installed until the INTEVEP network is operational. Cassette tapes from these recorders shall be returned to LLNL for transcription and for preliminary processing.

b) Seismic Refraction Data Collection.

After the INTEVEP Q-log recording system is installed at permanent sites LLNL shall install additional stations with the assistance of INTEVEP personnel at up to 20 temporary sites located along refraction profile lines. Data from several planned timed explosions (1 to 3 tons) shall be recorded using LLNL portable stations and combined with digital data from INTEVEP's digital stations in order to develop an accurate model of the shallow crustal structure.

c) Crustal Model Inversion.

LLNL shall provide INTEVEP with six computer programs and technical assistance for the development of a crustal model for relocating current and historic seismicity in the area of the Lake Maracaibo Bolivar Coast.

LLNL shall perform a preliminary interpretation of the data collected in Subtasks a) and b) for shallow structure in order to locate any seismicity recorded by the combined network of permanent and portable digitally recorded stations. Final interpretation and model development shall be done by INTEVEP upon conversion of the SAC program to the INTEVEP IBM 4341, transfer of crustal model inversion programs, and the availability of seismic reflection profiles and velocity models near the network.

d): Source Mechanism Studies.

LLNL shall assist INTEVEP personnel in the analysis of focal mechanisms for selected events from data recorded in Subtask 6). In addition to first motion studies, moment tensor inversions and SV/P amplitude analysis shall be conducted, data allowing, on a subset of the events. Finally, spectral techniques shall be applied to estimate stress drop and other relevant source parameters. LLNL shall also determine if composite focal mechanisms can be inferred on a routine basis with only the INTEVEP network.

e): Documentation and Training for Use of Computer Programs for Geophysical Analyses.

LLNL shall provide documentation for computer programs described in Task c) above. These programs include programs for seismic data display and processing (SAC), modeling of seismic source mechanisms, inversion of travel times for velocity structure and location refinement, and other

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aspects contained in these tasks. LLNL shall provide greater detail on specific programs on request. LLNL shall also train INTEVEP personnel to use these programs at LLNL or on their IBM computer.

f): Conversion of SAC for the IBM 4341 Computer.

LLNL programmers shall assist INTEVEP computer programmers and provide information necessary for SAC to be implemented on INTEVEP's IBM 4341. LLNL shall provide SAC to INTEVEP on the understanding that SAC cannot be copied or transferred out of the PDVSA's (Petroleos de Venezuela S.A.) system. INTEVEP shall provide LLNL with a copy of the FORTRAN source code for the version of SAC which INTEVEP develops for the IBM 4341.

Task 2: Seismic Hazard Evaluation.

A decision to include this task shall be made by the Parties at a later date and, if included, shall be the subject of a future Amendment to the Implementing Agreement.

C. <u>Theoretical Studies on Compaction</u>

Task 1: DOE and INTEVEP shall jointly conduct an exhaustive review of the literature to establish the state-of-the-art with respect to conceptual and mathematical theories of compaction and its relationship to subsidence.

Task 2: DOE and INTEVEP shall jointly review the existing theories, laboratory methods, field methods, and synthesize them into one state-of-the-art report.

D. Petrophysics Relating to Compaction

Task 1: Laboratory Measurements on Disturbed and Undisturbed Core for Parameter Evaluation.

LLNL shall measure the effects of disturbance on the mechanical properties of clay and sandstone samples provided by INTEVEP by contrasting the behavior of the cores as furnished with the cores further disturbed by pressurization followed by depressurization. Results shall be furnished in the form of P-V curves and a tabulated set of PV and acoustic velocity values for each test. The data shall be interpreted and conclusions presented at the conclusion of this task by LLNL. INTEVEP shall collect and ship appropriate amount of 4-1/2" core samples to LLNL.

Task 2.: Laboratory Determination of Parameters for Model Simulations.

LLNL shall perform three types of laboratory measurements to define the behavior of the relatively undisturbed rock core furnished for laboratory testing by INTEVEP. Results shall be analyzed, conclusions presented and the data sets provided by LLNL to INTEVEP at the conclusion of this task, from which model parameters shall be determined. The data sets to be provided are Mohr-Coloumb failure envelopes, elastic moduli, high pressure compressibilities, and thermal conductivities and diffusivities. INTEVEP shall select, prepare, and ship core samples to LLNL.

Task 3: Laboratory Studies of Long-term Creep Compaction of Reservoir Materials Under Appropriate Pressures and Temperatures.

LLNL shall subject rock samples provided by INTEVEP to constant stress long enough to determine a constitutive relationship useful in predicting the long-term response of the samples. LLNL shall test both sandstone and shale samples under controlled conditions of confining pressure, pore pressure, temperature and time. Acoustic velocities shall be measured periodically and the changes in sample volumes shall be determined. Data shall be reported by LLNL in graphical and tabular form and shall present the creep compaction as functions of pressure, temperature and time. The data shall be analyzed and conclusions drawn. INTEVEP shall collect and ship appropriate samples to LLNL.

Task 4: Familiarization of INTEVEP Personnel in Advanced Laboratory Techniques and Apparatus.

A decision to include this task shall be made by the Parties at a later date and, if included, shall be the subject of a future Amendment to the Implementing Agreement.

ARTICLE 3

A. DOE shall contribute $25,000 in U.S. dollars to the cost of carrying out Paragraph C of Article 2 of this Implementing Agreement, subject to the availability of appropriated funds. Except for the $25,000 contribution by DOE, all costs attributable to this Implementing Agreement, including but not limited to research, reports, travel, salaries and associated expenses, shall be borne by INTEVEP.

B. INTEVEP shall provide to DOE a financial contribution in U.S. dollars to support its share of the work in accordance with procedures to be identified by DOE prior to the first deposit.

C. Unless otherwise agreed by the Joint Steering Committee, the total amount to be paid by INTEVEP to DOE over the two-year period of this Implementing Agreement, subject to the availability of appropriated funds, shall not exceed 840,000 in U.S. dollars for carrying out Sections A, B and D of Article 2 of this Implementing Agreement.

D. LLNL shall be responsible for the transport, including safekeeping and insurance en route, of DOE components and testing equipment to be used in Venezuela under Sections A and B, from the United States by plane or ship to an authorized port of entry in Venezuela convenient to the ultimate destination. INTEVEP shall reimburse DOE for all expenses incurred for the transport, including safekeeping and insurance en route, of these components and equipment. INTEVEP shall be responsible for the transport, including safekeeping and insurance en route, of these components and equipment, from the authorized port of entry in Venezuela

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to the ultimate destination and shall be responsible for the return of these components and equipments, safekeeping and insurance en route, to an authorized port of entry in the United States convenient to the ultimate destination.

ARTICLE 4

The Parties shall support the widest possible dissemination of information arising from this Implementing Agreement in accordance with Article 2 of the Annex to the Energy R&D Agreement. If a Party has access to proprietary information as defined in Article 2 of the Annex to the Energy R&D Agreement which would be useful to the activities under this Implementing Agreement, such information shall be accepted for the tasks only on terms and conditions as agreed in writing by the Parties.

ARTICLE 5

Rights to any invention or discovery made or conceived in the course of or under this Implementing Agreement shall be distributed as provided in paragraph 1 of Article VI of the Energy R&D Agreement. As to third countries, rights to such inventions shall be decided by the Joint Steering Committee.

Each Party shall take all necessary steps to provide the cooperation from its inventors required to carry out this Article. Each Party shall assume the responsibility to pay awards or compensation required to be paid to its own nationals according to its own laws.

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ARTICLE 6

The existing terms and conditions of the Energy R&D Agreement shall continue and remain in full force and effect notwithstanding the terms of this Implementing Agreement. Articles 3, 4, 5, 6, 7, and 8 of the Annex to the Energy R&D Agreement are hereby incorporated by reference.

ARTICLE 7

This Implementing Agreement shall enter into force upon the later date of signature and shall remain in force for a period of two years. It may be amended or extended by mutual written consent of the Parties in accordance with Article V of the Energy R&D Agreement.

ARTICLE 8

This Implementing Agreement may be terminated at any time at the discretion of either Party, upon six (6) months advance notification in writing to the other Party by the Party seeking to terminate the Implementing Agreement. Such termination shall be without prejudice to the rights which may have accrued under this Implementing Agreement to either Party up to the date of such termination.

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Done in Washington, D. C., and Caracas, Venezuela.

THE JOINT STEERING COMMITTEE

On behalf of DOE	On behalf of MEMV
Member Keith Frye	Member Manuel Alayeto
Member George Stosur	Member Enrique Vasquez
Alternate Member Robert Folstein	Member Luis Giusti
Date	Dec. 03, 1984. Date

APPENDIX
TO
ANNEX IX

ARTICLE 2

Statement of Work to be Performed by LLNL

A. Geophysical Probing

Task 1: DOE shall provide INTEVEP with a detailed review of the geophysical techniques that have merit for determining the nature of fractures at three specific sites on the Bolivar Coast. Each of the above sites shall be considered in terms of its own underground characteristics, such as saturation, fluid composition, and material-type. The techniques to be evaluated shall include, but shall not be limited to, surface based electromagnetic radar, electrical self-potential, two-loop mutual impedence, electrical resistivity, seismic transmission, excitation-of-the-mass, borehole-to-borehole signal-transmission, and seismic emission. This task is estimated to take six weeks following authorization by project managers to commence.

Task 2: Crack and Void Detection

<u>Objective</u>: Develop and demonstrate surveillance methods for detecting potentially hazardous voids and cracks within and beneath the dikes.

<u>Rationale</u>: Geophysical methods have many roles in assessing shallow hazards: identification of appropriate locations for more expensive detection or maintenance efforts, exploration where drilling is not allowed, extrapolation of features detected in exploratory borings, and confirmation that engineering solutions are functioning as planned. LLNL personnel have evaluated candidate geophysical techniques for reconnaissance of the dikes and selected three methods to be evaluated further.

<u>Description</u>: We propose three methods for monitoring the dikes for potential hazards. These are Mutual Impedence, Magnetometric Resistivity, and Excitation of the Mass. The first two techniques should be valuable for detecting and delineating potentially hazardous voids in the dikes (as well as serving as checks on each other), and the third for detecting seepage paths under the dikes. In our opinion, the Mutual Impedence technique would appear to show the highest payoff, and therefore our plan will emphasize this technique.

The evaluation of the Mutual Impedence Method will proceed in several stages. First, an accurate description of a representative section of the dike will be compiled. Second, physical and computer modeling will be used to calculate the anomalies caused by postulated voids and cracks, and to choose an optimum source and receiver configuration, frequency range and loop size. Based on these studies, LLNL will design a system and plan an experimental program to test it. LLNL and INTEVEP will jointly review this plan and decide whether to proceed with the third step, system fabrication and field tests.

Outcome: INTEVEP will receive recommendations for implementation of a reconnaissance system for monitoring potentially hazardous conditions within the dikes.

Proposed Schedule:

2.1 INTEVEP will:

A. Acquire samples of materials from which dikes are made for purposes of electrical characterization. Alternatively, measured values or data from which they can be derived would be acceptable.

B. Acquire detailed drawings of a representative dike. (August, 1984)

2.2 Laboratory Measurements.

LLNL will measure the electrical characteristics of the materials from 2.1A (September 1984).

2.3 Computer Modeling.

Computer modeling experiments for determination of system response to variations in loop spacing, orientation, and frequency of operation. LLNL will evaluate the three systems mentioned above under "Description" and study in detail those most appropriate. LLNL would determine which combination of system design parameters gives the maximum response for expected anomaly types. (October-November, 1984)

2.4 Experiment and System Design (December 1984-January 1985)

LLNL will use the information obtained from 2.3 to design the "best" system and evaluate it. LLNL will provide intermediate report on activities completed and feasibility of method (January, 1985).

2.5 LLNL and INTEVEP decide whether to proceed with fabrication and field evaluation as outlined in 2.6 through 2.11 below (February, 1985).

2.6 Prepare for First Field Deployment

A. Buy or build system

B. System test at LLNL

C. Travel arrangements

D. Arrange for shipping of equipment

2.7 Perform First Field Experiment

Our purpose here would be to determine such things as the sensitivity of the various techniques to the natural background as well as anomalous features. We also seek to check each technique for its range of validity and to compare the techniques to each other.

2.8 Data Reduction and Planning

Here we reduce the data from the first field experiment and plan for the second experiment.

2.9 Perform Second Field Experiment.

2.10 Data Reduction and Interpretation.

2.11 Write Final Report and Make Recommendations for Dike Monitoring System

Estimated Cost:

Cost to decision point (Item 2.5) not to exceed $100,000. Estimated cost of total project would be an additional $200,000.

Task 3: Fullwave Recording of Data from Acoustic Emission Experiment

Final decision to include or not to be made at later date.

Task 4: Swept-Frequency Radar Development.

Deferred; final decision to be made based on fixed-frequency radar investigation by INTEVEP.

B. Seismic Hazard Studies

Objective: To assist INTEVEP in the collection and analysis of data required to determine the seismic hazard for the dikes.

Rationale: A significant possible hazard to the dikes might result from a number of geological hazards. These geological hazards include:

(1) Ground rupture under or very near the dikes due to a strong earthquake.
(2) Ground failure due to liquifaction during strong ground shaking due to a large earthquake.
(3) Structural damage to the dikes themselves due to strong ground shaking.

The determination of the likelihood of damage due to ground rupture requires an extremely accurate seismotectonic model which identifies all capable faults which might run under or very near the dikes, and their seismicity rates. Geological and seismological investigations which can aid in determining whether capable faults exist in the area include detailed geologic mapping and monitoring of microseismicity.

The hazards mentioned under (2) and (3) require the characterization of the strong ground shaking which might be produced at the dikes due to any nearby earthquake source zones. The decision as to when adequate information has been obtained for the characterization of the ground motion depends on the implementation of specific methodologies used to assess the earthquake ground

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motion parameters. The parameters that are generally accepted as being of engineering significance include peak values of ground motion (acceleration, velocity or displacement), spectral content, and duration of significant shaking. It is generally agreed that earthquake ground motion parameters are greatly affected by source factors, path effects (attenuation relationship), and local site conditions. Thus we must move from observable or modelable quantities to the final characterization of the ground shaking. Currently, this characterization is thought to be best described by a probabilistic hazard assessment which describes the errors in each observed or modeled quantity as well as can be done. For such methodologies the observables are well defined, they include some or all of the following: time and size of the last motion on a given fault, recurrence rate, slip rate, fault length, seismicity rate, and location.

In addition, the seismic source zones need to be well defined, this definition includes the requirement to adequately model significant earthquakes. Thus, modeling requires the definition of the magnitude, moment, and radiation pattern for such events.

Once the sources are well defined (that is, the probability of a given event occurring at a given distance is defined), we need to model the actual effect at the dikes. This requires the determination of all pertinent path effects, these include the attenuation of the strong shaking along the propagation path, and the determination of local effects such as soil amplification or damping.

This hazard determination rests, then, on a well-defined seismotectonic model of the area, followed by the determination of design basis earthquakes used to model the effects of strong shaking on the dikes. The formulation of an improved seismotectonic model requires estimates of both current and historic seismic activity in eastern Venezuela, accurate location of earthquakes and accurate determination of the source mechanisms. Geological studies can provide a list of potential faults which can be identified as associated with the seismic activity, provided the seismicity is accurately located, so that its association with a given fault zone is unequivocal. This requires accurate, rapid location and analysis of earthquakes within about 100 km of the dikes. This can be accomplished through the installation of a multi-station seismic network which has been calibrated by a number of timed high-explosive shots. The velocity structure within the network can then be determined by simultaneous inversion of earthquake phase data (including P and S waves) and data from the shots. This velocity structure can then be used to relocate both the ongoing and historical seismicity. Following the relocation, accurate focal mechanisms can be determined and seismicity can then be associated with mapped features.

Description:

Task 1: Structure and Seismicity

a) Seismic Network Installation/Data Acquisition.

We propose to assist INTEVEP in developing a model for relocating current and past seismicity affecting the seismic hazard in the eastern Lake Maracaibo region by temporarily deploying portable digital recorders and our central recording system to collect waveform data from the INTEVEP network.

We will deploy sensors at 6 proposed network station sites and record seismicity prior to installation of the Dyneer Q-log system. These data will be recoded using LLNL's PDR-2 recorders. An additional 6 channel PDR-2 recorder would be installed to record seismicity from the seismic network operated by the Universidad de los Andes in Merida. This sub-task would require a visit by three LLNL employees to install these instruments and train INTEVEP or University personnel to service the recorders. These portable recorders would remain installed until the INTEVEP network is operational. Cassette tapes from these recorders would be returned to LLNL for transcription and for preliminary processing. LLNL would provide initial analyses and copies of the data on 9-track tapes.

b) Seismic Refraction Data Collection

After the INTEVEP Q-log recording system is installed at permanent sites (in the second quarter of 1984), LLNL proposes to install additional stations with the assistance of INTEVEP personnel at up to 20 temporary sites located along refraction profile lines. INTEVEP is responsible for collection of data from their permanent station network which will free LLNL equipment currently deployed for redeployment at other temporary recording sites. Only the station at Merida will be left in place for recording data from the seismic network operated by the Universidad de los Andes. Data from these additional sites will either be recorded on-site using LLNL portable digital recorders or, if necessary, will be telemetered to an LLNL recorder site using LLNL equipment. We will record the planned timed explosions (1 to 3 tons) using our portable stations and combine these data with digital data from INTEVEP's digital stations in order to develop an accurate model of the shallow crustal structure within the permanent network. The explosions will be detonated by INTEVEP at widely spaced shot points within the network; ensuring different directions for rays propagating across the network and proper sampling of the velocity structure. Some of the explosions will be located in the source region of the nearest active seismic belt in order to provide a comparison for accurate relative locations in this region. Recording of any seismicity is considered to be of secondary importance to obtaining recordings of the explosions. We would primarily assist INTEVEP by recording these data and transcribing the data from these stations and other digitally recorded seismic data to a format which is compatible with their IBM computer. A preliminary analysis will consist of picking arrival times for seismic waves recorded from earthquakes and explosions. Further analysis is contained in Subtasks c) and d).

c) Crustal Model Inversion

LLNL has recently conducted a project in the Livermore Valley, California, which is identical to INTEVEP efforts to produce a crustal model for relocating current and historic seismicity. The main programs which are useful specifically for modeling are:

RAY2D: VELINV: A layered model inversion program using large joint equations

VELR: A layer reference and model inversion with matrix splitting and inclusion of both P and S models (expandable to a 3-D perturbation modeling)

VELEST: A layered model inversion program for a 1-D model

LQUAKE: Hypocenter calculation program

HYPO71: Lee and Lahr (1971) hypocenter location program

plus other supplementary programs referred to in Subtask e). We can provide programs, advice, and computational capabilities in these areas. We would first provide basic documentation of our programs to INTEVEP. Later, INTEVEP personnel should visit LLNL to become familiar with their operation (ideally, using their own data). The next part of the task is to transfer these programs to INTEVEP and aid during installation on their computer.

We would also perform a preliminary interpretation of the data collected in Subtasks a) and b) for shallow structure in order to locate any seismicity recorded by the combined network of permanent and portable digitally recorded stations. Final interpretation and model development would be done by INTEVEP contingent upon conversion of SAC to the IBM 4341, transfer of crustal model inversion programs, and the availability of seismic reflection profiles and velocity models near the network. We anticipate these models would be published under joint INTEVEP and LLNL authorship.

d): Source Mechanism Studies

An essential aspect of the seismic hazard analysis is focal mechanism studies of earthquakes. As part of the seismicity study, we propose additional analysis directed toward source studies of earthquakes to aid in association of particular models for faulting in specific source regions.

Data recorded with the INTEVEP seismic network would be combined with data from the LLNL portable deployment to give adequate station density. We would assist INTEVEP personnel in the analysis of focal mechanisms for selected events. In addition to first motion studies, moment tensor inversions and SV/P amplitude analyses may be possible on a subset of the events. Finally, spectral techniques can be applied to estimate stress drop and other relevant source parameters. This study will also determine if composite focal mechanisms can be inferred on a routine basis with only the INTEVEP network. It should be noted that final interpretation and model development is contingent upon other portions of this proposal.

e): Documentation and Training for Use of Computer Programs for Geophysical Analyses

LLNL will provide documentation for programs described in the other sections of this proposal. These programs include programs for seismic data display and processing (SAC), modeling of seismic source mechanisms, inversion of travel times for velocity structure and location refinement, and other aspects contained in these tasks. We will provide greater detail on specific programs on request. We will also train INTEVEP personnel to use these programs at LLNL or on their IBM computer.

f): Conversion of SAC for the IBM 4341 Computer

SAC (Seismic Analysis Code) is a general purpose interactive analysis program designed for the study of sequential data, especially time-series data. Emphasis has been placed on analysis tools needed by research seismologists in the detailed study of seismic events. Current analysis capabilities include normal arithmetic operations, Fourier analysis, infinite impulse response (IIR) and finite impulse response (FIR) filtering, automatic and manual time and amplitude picking, signal stacking, noise estimation, Hilbert transform, cross-correlation, decimation, interpolation, Wiener filtering, windowing, phase-unwrapping, instrument correction, and three component projection. Each signal is stored on disk in a separate file containing the data preceded by a generalized header record. Up to 100 such signals of arbitrary size can be processed simultaneously. Smaller portions of a data file can be identified and processed using values entered manually or stored in the header as delimiters. SAC also contains a very extensive graphics capability. Default values for each graphic attribute are chosen so that a plot can be generated with little effort. At the same time, the user has complete control over the picture display. This integration of analysis and graphical capabilities into a single system is one of SAC's more powerful features. Written in Fortran 77, SAC was designed to be both modular and transportable. Array dimensions that affect program size are easily adjustable. All machine and graphics library dependent coding is isolated in a small set of low level subroutines allowing easy conversion to other computers.

If INTEVEP desires conversion for the IBM 4341, LLNL programmers would instruct INTEVEP computer programmer and provide information necessary for SAC to be implemented on INTEVEP's IBM 4341. Training for implementation on the IBM 4341 will require approximately one man-month of effort. SAC is a program copyrighted by the University of California and LLNL will provide it to INTEVEP on the understanding that SAC cannot be copied or transferred out of the PDVSA's (Petroleos de Venezuela S.A.) system. We also require that INTEVEP provide LLNL with a copy of the FORTRAN source code for the version of SAC which INTEVEP develops for the IBM 4341.

Task 2: Seismic Hazard Evaluation

(It has been decided to defer decision on inclusion of this task until 1985.) Proposed task description follows:

This task has two objectives:

Objective 1: To estimate the seismic hazard at five selected sites along the dike, in terms of peak ground acceleration and pseudo relative velocity spectra.

Rationale: Prediction of the dynamic behavior of the dikes under seismic loading is heavily dependent on the physical models (i.e., material properties, mechanical properties, geometry, etc.) and on the type of seismic loadings. It is now recognized that the uncertainty in the loading is generally the dominant factor of uncertainty in the dynamic analyses. As a result, it is important to quantify the uncertainty in the hazard as best as possible. The random uncertainty as well as the systematic (or model) uncertainty has to be expressed clearly and accounted for. Until recently, no methodology existed to include the systematic uncertainty. Several are now available, the approach of which is generally of the ad-hoc engineering type.

Under a contract with NRC, LLNL has developed a rigorous, systematic methodology to be applied to the eastern U.S. which should also be applicable to the Lake Maracaibo region in Venezuela. The general concept is to introduce the systematic uncertainty at every level in the analysis by making extensive use of experts' opinions, thus by using every possible physical interpretation of the data and scientifically deriving the levels of confidence (probabilities) for each interpretation.

Description: Two types of data are necessary to perform this analysis. The first type is the description of the seismic activity, in the form of a set of seismic zonation maps and their associated seismicity parameters. The second type is the description of the ground motion attenuation as a function of distance from the source and magnitude (or intensity) of the earthquake. These data will be provided by two sets of experts chosen for their general knowledge of the area considered and their expertise in the fields of seismology and earthquake engineering. For the first panel of experts (ZSE) on zonation and seismicity, we recommend no less than five (5) members. For the second panel (GME) on ground motion modeling, 5 members would also be advisable, although as little as 3 would be permissible. The choice of the experts will be made in concensus between INTEVEP staff and LLNL.

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LLNL will prepare and send the questionnaires to the experts, collect their answers, and develop the actual computer files for use in the LLNL hazard code. This includes:

- digitization of the zonation maps (an average of 2 maps per ZSE)
- generate the files of seismicity parameters (1 file per ZSE)
- test of these files for consistency and correctness

LLNL will update its computer codes, make minor changes necessary to account for the specific needs of this analysis (primarily input-output changes and/or minor model changes).

An exhaustive sensitivity analysis will be performed to ascertain the relative importance of each of the parameters used in the analysis and determine if any more work is needed. It is assumed at this point that no major work in the field of ground motion modeling will be performed. Rather, the ground motion models will be derived from available models.

Objective 2: Transfer of the Technology to INTEVEP.

This includes transfer of codes and providing assistance in setting-up and use of the LLNL codes.

Rationale: The codes now available at LLNL have been developed for the CDC 7600 system and possess some features specific to LLNL, such as the plotting package. INTEVEP will need assistance in setting up these codes on their computer system.

Description: The codes will be provided on tapes along with users manuals. INTEVEP's staff will set these codes on their system, however, because of the complexity of such codes, it is recommended to detach an LLNL employee knowledgeable with the codes to INTEVEP to provide assistance in the setting-up and training in the use of the codes for a total of 1 month. (Possibly in several smaller sojourns.)

Proposed Schedule - Task 1

a)	Deploy recorders	March-April 1984
	Analysis	May-December 1984
b)	Deployment	July-August 1984 (after installation of INTEVEP network)
	Analysis	September 1984-March 1985
c)	Model Inversion	December 1984-March 1985
d)	Mechanism Studies	March 1985-June 1985
e)	Program Training	May-December 1984 (1 man-week to 2 man-months)
f)	SAC Conversion	May-July 1984

Proposed Schedule - Task 2:

Objective 1:

1. Choose experts (with INTEVEP)
2 Prepare and send zonation/seismicity
3. Prepare and send ground motion questionnaire
4. Digitize maps, develop seismicity files
5. Develop ground motion files
6. Finalize input files
7. Perform analysis
8. Final report

Objective 2:

1. Provide codes
2. Visit at INTEVEP's location for assistance and training

Estimated Costs:

Task 1:

a)	$ 52,000
b)	$150,000
c)	$ 30,000
d)	up to $24,300
e)	up to $24,300
f)	$ 10,000
[Task 2:	$120,000] tentative

C. Theoretical Studies on Compaction

Task 1: DOE and INTEVEP shall jointly conduct an exhaustive review of the literature to establish the state-of-the-art with respect to conceptual and mathematical theories of compaction and its relationship to subsidence.

Task 2: DOE and INTEVEP shall jointly review the existing theories, laboratory methods, field methods, and synthesize them into one state-of-the-art report.

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D. Petrophysics Relating to Compaction

Task 1: Laboratory Measurements on Disturbed and Undisturbed Core for Parameter Evaluation.

Objective: To measure the effects of disturbance on the mechanical properties of clay and sandstone samples.

Rationale: Prediction of formation behavior at depth requires a validated numerical model and the appropriate physical property input data. These data will be derived from both the field (well, surface) as well as in the laboratory. It is inevitable that by testing of drill core in the laboratory, some disturbance of the core will occur either through the field coring operation, by depressurization and cooling or by preparation of the laboratory test samples from the rock core. It is proposed to evaluate the effects of this "disturbance" upon the physical (especially mechanical) properties of the core by contrasting the behavior of the core as furnished with core material further disturbed by pressurization using a fluid followed by depressurization along several loading/unloading paths.

Description: Three samples, two sandstones and clay or shale, will be tested. Pressure-volume tests will be run on each material as furnished. Each of the two sandstones will be disturbed (expanded) to two porosity values; the clay will only be tested in its as furnished state. Thus, a total of seven tests will be run at each of two temperatures: 20° and 150°C. Each test will be of the pressure-volume

(PV) type and in each, six-ten loading-unloading cycles will be accomplished up to a maximum pressure of 15,000 PSI. Volume changes will be determined by measurement of fluids expelled during pressurization. Only the fluid produced from the clay/shale will be analyzed for salinity. Acoustic velocities will be measured at selected points along each PV curve. Results will be furnished in the form of P-V curves and a tabulated set of PV and acoustic velocity values for each test. The data will be interpreted and conclusions presented.

Outcome: The data will demonstrate how much disturbance influences the mechanical properties of these materials. These results can be used to decide to what extent measurements on possibly disturbed core represents the parameters *in situ*. Furthermore, a method may be developed to determine (and correct for) the degree of disturbance from PV measurements on core material.

Proposed Schedule:

(1) INTEVEP collect, prepare and ship core samples (March-June 1984).

(2) LLNL reconfigure apparatus (June-July, 1984).

(3) LLNL perform measurements (August 1984-January 1985).

(4) Final Report (approximately March 1985).

INTEVEP Requirements: INTEVEP will collect and ship appropriate amount of 4-1/2" core samples to LLNL. Assumes core will be available in Livermore June 1, 1984.

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Cost: Not to exceed $60,000.

Task 2.: Laboratory Determination of Parameters for Model Simulations.

<u>Objective</u>: To provide parameters for models. The parameters to be provided are Mohr-Coloumb failure envelopes, elastic moduli, high pressure compressibilities, and thermal conductivities and diffusivities.

<u>Rationale</u>: These parameters are required and LLNL can measure them over the appropriate pressure and temperature ranges.

<u>Description</u>: Three types of laboratory measurements are suggested to define the behavior of the relatively undisturbed rock core (whole core furnished for laboratory testing by INTEVEP) for the purpose of model input.

(a) The first would be Mohr-Coloumb (M-C) failure envelope curves based on six to eight measurements each on one sandstone and one clay. Both would be tested at 20° and 150°C over a pressure range up to 15,000 PSI. Data will be furnished in the form of M-C envelopes and data tables. Several samples will be strain gaged to give elastic moduli. Results will be analyzed and conclusions presented.

(b) The second measurement for model input would be P-V testing to very high pressure to define the grain compressibility (and thus elastic constant) of one sandstone at 20°C. Pressures would range to 450,000 PSI with several unloading/reloading cycles for comparison with data from task D-1.

(c) The third measurement for model input would include the determination of thermal conductivity and thermal diffusivity under pressure to 8000 PSI and temperatures to 250°C. Two sandstones and one clay would be tested. Curves of conductivity and diffusivity, vs. pressure and temperature will be furnished as well as tabulated data. Results will be analyzed and conclusions drawn.

Outcome: INTEVEP will be given data sets from which model parameters will be determined.

Proposed Schedule:

(1) INTEVEP select, prepare, and ship core samples (March-June 1984). Assumes core available June 1, 1984, in Livermore.

(2) Measurements at LLNL

(a) M-C envelopes	June-December 1984
(b) Compressibility	June-December 1984
(c) Thermal Properties	October 1984-March 1985

(3) Final report June 1985

Cost Estimates: Not to exceed $80,000.

Task 3: Laboratory Studies of Long-term Creep Compaction of Reservoir Materials Under Appropriate Pressures and Temperatures.

Objective: To determine a constitutive law relating effective stress, volume, temperature, and time for the Bolivar Coast and Faja reservoir rocks as well as to elucidate the mechanisms of long term creep compaction of these rocks.

Rationale: Many compaction producing processes take a long time. Consequently, the response of a rock sample to an instantaneous reduction in effective stress consists of two parts: the "instantaneous" response and long-term creep compaction. Routine laboratory measurements are of short duration and do not detect the long-term component of deformation. In this task, rock samples will be subjected to constant stress long enough to determine a constitutive relationship useful in predicting the long-term response of the reservoir and associated rocks for different production schemes.

Description: We will study both sandstone and shale under controlled conditions of confining pressure, pore pressure, temperature and time. Two sandstones and one shale will be tested at both 20^{o} and 150^{o}C under hydrostatic loading. V_p and V_s will be measured periodically. The change in sample volume will be determined by measurement of the fluid expelled from the sample at constant pore pressure and effective stress. Data will be reported in graphical and tabular form and will present the creep compaction as functions of pressure (lithostatic or effective), temperature and time. The data will be analyzed and conclusions drawn.